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Effects of transplant type, plant growth-promoting rhizobacteria, and soil treatment on growth and yield of strawberry in Florida

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Abstract

The effects of transplant type and soil treatment on growth and yield of strawberries (*Fragaria* x *ananassa* Duch.) produced in annual hill culture were evaluated for three years in Florida field trials. 'Sweet Charlie' and 'Camarosa' strawberry transplants were propagated as bare root, plug, and plugs amended with a plant growth-promoting rhizobacterial (PGPR) treatment, LS213. The transplant treatments were evaluated in combination with methyl bromide, 1, 3-dichloropropene (Telone II), an unregistered iodine-based compound (Plantpro 45), and untreated soil. 'Camarosa' plugs amended with LS213 had higher overall yields than bare root transplants in all three years. Both 'Camarosa' and 'Sweet Charlie' plug and LS213 plug plants produced yields approximately two weeks earlier than bare root transplants in all years. Regardless of transplant type, and in both consecutive years of Plantpro 45 and Telone application, treatment with Plantpro 45 resulted in smaller and less healthy root systems than other soil treatments, and treatment with Telone resulted in yields comparable to methyl bromide.

Abbreviations: PGPR – plant growth-promoting rhizobacteria; 1, 3-D – 1,3-dichloropropene; MeBr – methyl bromide

Introduction

Methyl bromide has provided strawberry (*Fragaria* x *ananassa* Duch.) growers with reliable control of nematodes, weeds and soilborne pathogens since it was first reported to control Verticillium wilt in 1961 (Wilhelm et al., 1961). The loss of methyl bromide as a soil fumigant will significantly impact strawberry production in the United States, particularly in California and Florida where most strawberry growers rely exclusively on this broad-spectrum fumigant to disinfest soil prior to planting. In California, 42% of the total amount of methyl bromide used is for preplant soil fumigation in strawberries (CADPR, 2001), while 9% of the methyl bromide used in Florida is for this application (FASS, 1999).

Increased strawberry vigor and yield with methyl bromide fumigation has been demonstrated repeatedly (Yuen et al., 1991) and was recently quantified in Florida where production was reduced by 54% and 68% in consecutive years in nonfumigated compared to methyl bromide-fumigated soil (Chandler et al., 2001). Similar results, obtained in an area without high levels of lethal strawberry pathogens, were also observed in California (Fort et al., 1996) where strawberry vigor and fruit yield were substantially increased with methyl bromide fumigation without identifiable pathogen problems present. Important soilborne fungal pathogens of strawberry controlled by soil fumigation with methyl bromide formulations include *Phytophthora fragariae*, *P. cactorum*, *Colletotrichum acutatum*, and several species of *Verticillium* (Wilhelm, 1998). Black root rot is another important disorder believed to be caused by interactions among

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several factors including fungal pathogens, nematodes and a variety of soil conditions (Wilhelm, 1998). In Florida, the most serious nematode parasite of strawberry currently controlled by fumigation is sting nematode (*Belonolaimus longicaudatus*).

In recent years, there has been considerable research on chemical alternatives to methyl bromide for strawberry production. These alternatives include 1,3-dichloropropene (1, 3-D), dazomet, chloropicrin, and metam sodium. However, certain issues surrounding alternatives remain unresolved, including performance inconsistencies, label restrictions regarding use, and the need for personal protective equipment to be worn in the field during application (Carpenter et al., 2001; Noling and Gilreath, 1998). Recent improvements in technology for broadcast application of 1, 3-D improved product performance and eliminated the need for personnel to be present in the field, thus minimizing issues regarding personal protective equipment (McAvoy, 2000). In order to implement effective chemical alternatives to methyl bromide, it will be necessary for growers to target specific pests and select the appropriate combination of control measures. It is likely that production systems including combinations of chemicals, as well as cultural and biological tactics, will be required to maintain strawberry yields at economically viable levels in the absence of methyl bromide.

Cultural and biological approaches that may be incorporated into strawberry production systems include modification of water use practices, application of biological control agents and reduced-risk chemicals, and incorporation of traditional or induced host resistance. One cultural practice typically used in strawberry production that has the potential to be modified to reduce chemical applications is the use of bare root transplants. Many serious strawberry root pathogens found in production fields often originate on planting material grown in soil (Butler et al., 2002). Also, establishment of bare root transplants in the field requires extensive use of overhead irrigation for several weeks after transplanting. These irrigation practices aggravate problems with many pathogens, leach preplant herbicides and fertilizer from soil, and increase weed pressure. The use of transplants produced in a soilless growth medium as plugs would eliminate some of the problems associated with the establishment of bare root transplants. Additionally, use of plugs would provide an alternative to methyl bromide fumigation of soil in strawberry nursery production, where it has been difficult to identify alternative fumigants that do not negatively impact runner plant production (Larson and Shaw, 2000). Other advantages of plug transplants over bare root transplants include improved stand establishment and plant vigor, and earlier flowering and fruit set (Morey, 2001; Sances, 2000). It has also been demonstrated that under stressful conditions, plug transplants produce higher yields than bare-root transplants (Waldo and Duval, 2001).

Transplant media as a means for introduction of biological agents is currently being investigated in a variety of crops. Kurze et al. (2001) evaluated a chitinolytic rhizobacterium, *Serratia plymuthica* strain HRO-C48, as a bare root transplant dip for strawberries and had good success in reducing disease caused by *Verticillium* and *Phytophthora* and increasing yields. Soil-less transplant media such as that used for production of strawberry plugs, amended with a formulation of plant growth-promoting rhizobacteria (PGPR) designated LS213 (Gustafson LLC, Plano, TX) has been shown to improve plant vigor, reduce disease severity and increase yield of tomato, pepper (Kokalis-Burelle et al., 2002), muskmelon and watermelon (Kokalis-Burelle et al., 2003) in Florida. LS213 contains the PGPR isolates *Bacillus subtilis* strain GBO3 and *Bacillus amyloliquefaciens* strain GB99 in a formulation that also includes chitin, an organic material previously shown to elicit low levels of resistance responses in tomato (Benhamou et al., 1998).

The objectives of this research were (1) to evaluate bare root, plug, and PGPR amended plug strawberry transplants for earliness and yield and (2) to evaluate the three transplant types in combination with methyl bromide alternative soil treatments. The objectives are examined for both ‘Camarosa’ and ‘Sweet Charlie’ cultivars, which currently constitute 70–90% of the strawberry acreage in Florida.

Materials and methods

Experimental design

Field trials were conducted in the fall of 1998, 1999, and 2000 at the Uniroyal Chemical Company Inc., Florida Research Station, Sanford, FL. Two trials were performed each year, one for ‘Sweet Charlie’ and one for ‘Camarosa’.

Experiments contained split plots with three subplots consisting of the three transplant types. Main plots consisted of two soil treatments in 1998, and four soil treatments in 1999 and 2000. Main plots were arranged in a randomized complete block design with three replications in 1998 and four replications in 1999 and 2000. Main plot treatments in 1998 were: (1) Untreated soil and (2) methyl bromide 98:2 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds. Mainplots in 1999 and 2000 were: (1) Untreated soil, (2) methyl bromide 67:33 MeBr:chloropicrin at 425 kg ha^{-1}, shank injected in beds 10 days prior to planting, (3) 1, 3-D (Telone II, Dow AgroSciences LLC, Indianapolis, IN) at 94.6 l ha^{-1}, broadcast shank injected 14 days prior to bedding), and (4) Plantpro 45 (Ajay North America, LLC, Powder Springs, GA) at 890 l ha^{-1} applied in bed through two high flow rate (emitters spaced at 10 cm) drip irrigation lines, 14 days prior to planting. Plantpro 45 is an unregistered, water-soluble, iodine-based compound currently being investigated as a reduced-risk methyl bromide alternative. All main plot soil treatments were applied under 30-μm-thick low-density polyethylene mulch in a typical annual hill plasticulture system. The 98:2 MeBr:chloropicrin concentration was the commercial standard in 1998 and the 67:33 concentration was standard in 1999 and 2000. Planting beds were 20 cm in height, and 0.9 m wide, spaced 1.8 m apart. In 1998, a single central drip irrigation line was laid just below the soil surface (5 cm). In both 1999 and 2000, two drip irrigation lines were placed approximately 8 cm from the center of the bed to facilitate improved soil distribution of chemicals applied through the drip irrigation system.

Subplots were 6.1 m long with strawberries planted in double rows spaced at 30 cm. All transplants were produced in northern latitudes. Strawberry bare root transplants for each season were purchased from Parksdale Farms (Plant City, FL). Two types of plug transplants, produced by S and G Growers (Limestone, MN) were evaluated. Both types of plug transplants were produced from tip cuttings of strawberry varieties 'Camarosa' and 'Sweet Charlie', planted into 72 cell transplant flats and grown in a greenhouse for 10–12 weeks. Cuttings were rooted in two transplant mixes: Speedling peat-lite mix (Speedling, Inc., Bushnell, FL) and Speedling peat-lite mix containing LS213 concentrate (BioYield^{TM}, Gustafson LLC), a product containing two PGPR isolates (*Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% chitin carrier) at a rate of 40:1 (vol/vol) potting mix:PGPR formulation.

Strawberries were transplanted in early to mid October each year. Overhead irrigation was utilized over entire tests each year for approximately two weeks after transplanting to insure establishment of bare root transplants. Strawberries were fertilized with 34 kg ha^{-1} N and K_2O, broadcast in bed before planting, and fertigated weekly beginning at 2 weeks after transplanting through February at 0.34 kg ha^{-1}day^{-1} N and K_2O. From February through the end of the season, plants were fertigated weekly at 0.85 kg ha^{-1}day^{-1} of both N and K_2O (Hochmuth and Albregts, 1994). Fungicide (Captan 80 WP at 3.4 kg ha^{-1}, Micro Flo, Co., Memphis, TN) was applied on a 7–10 day preventative schedule for Botrytis control through the growing season beginning in November. Insecticides (Thiodan 50 WP at 2.3 kg ha^{-1}, FMC Corp., Philadelphia, PA; Sevin 80S WP at 3.4 kg ha^{-1}, Aventis CropScience, Research Triangle Park, NC; Guthion 2L EC at 840 mL ha^{-1}, Bayer Corp., Kansas City, MO) and miticides (Vendex 50 WP at 1 L ha^{-1}, Griffin, LLC, Valdosta, GA; Agri-Mek 15 EC at 740 mL ha^{-1}, Syngenta Crop Protection, Inc., Greensboro, NC; Omite 30 WP at 2.8 kg ha^{-1}, Uniroyal Chemical Co., Inc., Middlebury, CT) were applied as needed. Weeds were controlled mechanically between beds and were removed by hand in the beds as needed.

Yield and root health evaluations

Plots were harvested 1-2 times per week for a period of 14–17 weeks, depending on weather conditions and growing season. Only ripe, marketable fruit (no blemishes) were weighed and included in yield. After the final harvest each year, three plants/plot were evaluated for total root weight and general root condition. Root condition ratings were based on amount of healthy feeder rootlets present and on amount of root tissue necrosis and discoloration. Root condition ratings were based on a scale of 1–5 with 1 = healthy, abundant, light tan colored roots with no sign of necrosis, and 5 = absence of healthy feeder rootlets, root system totally discolored and necrotic. Isolations from necrotic strawberry roots produced a variety of fungi including *Rhizoctonia solani* and *Fusarium* spp. However, isolations to characterize strawberry root pathogens responsible for poor root condition ratings were not performed as part of these trials.

Statistical analysis

Data were statistically analyzed utilizing standard procedures including SAS general linear model (GLM) and least significant difference (LSD) analysis at the

5% level of probability (SAS Version 7.01, SAS Institute, Inc, Cary, NC). Variables were analyzed across main plot and subplot treatments where significant interactions between main and subplot treatments did not occur.

Results

'Camarosa'

For all three seasons, plug and LS213 plug plants had larger and healthier root systems than bare root plants, although this was not statistically significant in 1998 (Tables 1, 2 and 3). In 1998 and 2000, LS213 plugs had higher total yield than bare root transplants (Tables 1 and 3). In 1999, plug plants had the highest total yield of all transplant types, although none were significantly different from each other (Table 2). In 1998 and 2000, methyl bromide resulted in healthier root conditions than the untreated control, although no significant difference occurred in 1999. In all three seasons, methyl bromide treated soil consistently produced higher yield than plants in untreated soil (Tables 1, 2 and 3). Irrespective of transplant type, and in both consecutive years of Plantpro 45 application, Plantpro 45 resulted in smaller and less healthy root systems and lower yield than the other soil treatments (Tables 2 and 3). Although Telone root weight and root condition were not significantly different than the untreated control, Telone resulted in yields comparable to methyl bromide and greater than the untreated control (Tables 2 and 3). Both plug and LS213 plug plants produced yields approximately two weeks earlier every year in all soil treatments than bare root plants (data not shown).

'Sweet Charlie'

For all soil treatments in all three seasons, plug and LS213 plug plants had healthier root systems than bare root plants (Tables 4, 5 and 6). In all three seasons, plug plants and LS213 plugs had greater root weight than bare root plants (Tables 4, 5 and 6). While LS213 plug plants had greater yield than bare root plants in all three seasons, this increase was only statistically significant in 1999. Plug plants had greater yield than bare root plants in 1999 and 2000 but had reduced yield compare to bare root in 1998. In all three seasons, methyl bromide resulted in healthier roots than the untreated control (Tables 4, 5 and 6). Irrespective of transplant type in 1998 and 1999, methyl bromide resulted in greater root weight and yield than the untreated control (Tables 4 and 5). In 1999 and 2000, Telone and methyl bromide produced healthier root systems than the Plantpro 45 for all transplant types (Tables 5 and 6). For both 1999 and 2000, LS213 plants had healthier root systems in methyl bromide and Telone treated soil than in Plantpro 45 treated soil (data not shown). As with 'Camarosa', 'Sweet Charlie' plug and LS213 plug plants produced yields approximately two weeks earlier than bare root transplants in all three years of this study, regardless of soil treatment (data not shown).

Table 1. 'Camarosa' root weight, root condition, and total yield at the end of the season in Sanford, FL, 1998

	Root Weight (g)	Root Condition[1]	Total Yield (kg ha^{-1})
Transplant type			
Bare root[2]	79.76 a[3]	2.08 a	20720 b
Plug[4]	107.79 a	1.66 a	22675 ab
LS213 Plug[5]	102.26 a	1.75 a	24989 a
LSD (0.05)	32.38	0.63	3048
Soil Treatment			
Untreated	95.24 a	2.22 a	20281 b
Methyl Bromide[6]	97.97 a	1.44 b	25308 a
LSD (0.05)	26.44	0.52	2489

[1]Root condition rating = 1–5 (1 = healthy roots/no necrosis, 5 = total necrosis).
[2]Bare root transplants produced in soil.
[3]Means with the same letter are not significantly different.
[4]Plug transplants were produced by rooting runner tips in a peat-based (soil-less) potting mix.
[5]The LS213 formulation contains *Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% carrier, and is equivalent to the commercial product BioYield™ was added to peat-based potting mix before rooting of runner tip plants.
[6]Methyl bromide 98:2 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds.

Discussion

This research, conducted over three growing seasons in the same location in central Florida, consistently demonstrated that plug transplants had healthier roots, earlier yields, and higher total yields than bare root transplants. The addition of PGPR to plug transplants often, but not always, enhanced growth and yield of the two strawberry cultivars tested. Addition of LS213 to plugs resulted in a greater enhancement of growth

Table 2. 'Camarosa' root weight, root condition, and total yield at the end of the season in Sanford, FL for 1999

	Root Weight (g)	Root Condition[1]	Total Yield (kg ha^{-1})
Transplant type			
Bare root[2]	28.59 b[3]	4.27 a	9398 a
Plug[4]	41.75 a	3.37 b	9625 a
LS213 Plug[5]	39.87 a	3.12 b	9550 a
LSD (0.05)	6.27	0.31	1657
Soil Treatment			
Untreated	39.37 a[2]	3.38 b	9063 bc
Methyl Bromide[6]	40.33 a	3.42 b	10187 ab
Telone II[7]	43.08 a	3.24 b	11188 a
Plantpro 45[8]	24.16 b	4.31 a	7660 c
LSD (0.05)	7.25	0.36	1913

[1]Root condition rating = 1–5 (1 = healthy roots/no necrosis, 5 = total necrosis).
[2]Bare root transplants produced in soil.
[3]Means with the same letter are not significantly different.
[4]Plug transplants were produced by rooting runner tips in a peat-based (soil-less) potting mix.
[5]LS213 contains *Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% carrier (BioYield,TM Gustafson LLC) was added to peat-based potting mix before rooting of runner tip plants.
[6]Methyl bromide 67:33 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds.
[7]1,3-Dichloropropene (1,3-D, Telone II, Dow AgroSciences LLC, Indianapolis, IN) at 94.6 l ha^{-1}, broadcast shank injected 14 days prior to bedding.
[8]Plantpro 45 (Ajay North America, LLC, Powder Springs, GA) at 890 l ha^{-1} applied in bed through two high flow rate (emitters spaced at 10 cm) drip irrigation lines, 14 days prior to planting.

Table 3. 'Camarosa' root weight, root condition, and total yield at the end of the season in Sanford, FL for 2000

	Root Weight (g)	Root Condition[1]	Total Yield (kg ha^{-1})
Transplant type			
Bare root[2]	45.75 b[3]	3.03 a	9215 b
Plug[4]	60.43 a	2.25 b	11394 ab
LS213 Plug[5]	56.58 a	2.25 b	12683 a
LSD (0.05)	10.51	0.32	2385
Soil Treatment			
Untreated	59.80 a	2.73 a	8758 b
Methyl Bromide[6]	55.77 ab	2.07 b	11559 a
Telone II[7]	54.23 ab	2.48 a	12641 a
Plantpro 45[8]	47.21 b	2.76 a	11434 ab
LSD (0.05)	12.14	0.37	2754

[1]Root condition rating = 1–5 (1 = healthy roots/no necrosis, 5 = total necrosis).
[2]Bare root transplants produced in soil.
[3]Means with the same letter are not significantly different.
[4]Plug transplants were produced by rooting runner tips in a peat-based (soil-less) potting mix.
[5]LS213 contains *Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% carrier (BioYield,TM Gustafson LLC) was added to peat-based potting mix before rooting of runner tip plants.
[6]Methyl bromide 67:33 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds.
[7]1,3-Dichloropropene (1,3-D, Telone II, Dow AgroSciences LLC, Indianapolis, IN) at 94.6 l ha^{-1}, broadcast shank injected 14 days prior to bedding.
[8]Plantpro 45 (Ajay North America, LLC, Powder Springs, GA) at 890 l ha^{-1} applied in bed through two high flow rate (emitters spaced at 10 cm) drip irrigation lines, 14 days prior to planting.

and yield in 'Camarosa' than in 'Sweet Charlie', indicating this particular combination of bacterial isolates may be better suited to 'Camarosa' and that differences in varietal response may occur within crops. Additional studies are necessary to determine if the effects on root disease and plant growth seen here are primarily nutritional, a result of a systemic resistance response in the host plant, or antagonistic activity of PGPR in the rhizosphere.

Methyl bromide and Telone performed consistently and were comparable with respect to producing vigorous, healthy roots and acceptable yields, while treatment of soil with Plantpro 45 resulted in plants with smaller, less healthy roots and reduced yields compared to plants grown in untreated soil. The combination of methyl bromide or Telone with LS213 plugs produced the healthiest and highest yielding plants. Under plant stress conditions such as the phytoxicity observed with Plantpro 45, the LS213 plugs performed better than both other transplant types. Other researchers found similar results with standard plug transplants where transplant survival was better for plugs than for bare root plants, which reduced labor expense associated with replanting bare root transplants (Hochmuth et al., 2000; Waldo and Duval, 2001). Sances (2000) evaluated several organic and chemical alternatives to methyl bromide in California strawberry production and found that plug plants consistently produced higher yields than bare root transplants in several types of management systems including fumigation with methyl bromide:chloropicrin, Telone:chloropicrin, iodomethane:chloropicrin, and organic production.

Trends consistently seen in both cultivars were that plugs and LS213 plugs produced berries approximately two weeks earlier than bare root plants. Earlier

Table 4. 'Sweet Charlie' root weight, root condition, and total yield at the end of the season in Sanford, FL for 1998

	Root Weight (g)	Root Condition[1]	Total Yield (kg ha^{-1})
Transplant type			
Bare root[2]	32.09 b[3]	3.08 a	21078 a
Plug[4]	61.76 a	2.37 b	19639 a
LS213 Plug[5]	52.38 ab	2.37 b	22458 a
LSD (0.05)	23.39	0.55	5420
Soil Treatment			
Untreated	39.18 b	3.72 a	16213 b
Methyl Bromide[6]	58.30 a	1.50 b	25903 a
LSD (0.05)	19.10	0.45	4426

[1]Root condition rating = 1–5 (1 = healthy roots/no necrosis, 5 = total necrosis).
[2]Bare root transplants produced in soil.
[3]Means with the same letter are not significantly different.
[4]Plug transplants were produced by rooting runner tips in a peat-based (soil-less) potting mix.
[5]The LS213 formulation contains *Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% carrier, and is equivalent to the commercial product BioYield™ was added to peat-based potting mix before rooting of runner tip plants.
[6]Methyl bromide 98:2 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds.

Table 5. 'Sweet Charlie' root weight, root condition, and total yield at the end of the season in Sanford, FL for 1999

	Root Weight (g)	Root Condition[1]	Total Yield (kg ha^{-1})
Transplant type			
Bare root[2]	28.20 a[3]	3.46 a	6308 b
Plug[4]	32.81 a	2.76 b	12264 a
LS213 Plug[5]	33.28 a	2.61 b	11843 a
LSD (0.05)	6.87	0.40	1447
Soil Treatment			
Untreated	29.16 b	3.00 b	9275 b
Methyl Bromide[6]	38.66 a	2.32 c	12631 a
Telone II[7]	31.81 ab	2.74 bc	11281 a
Plantpro 45[8]	26.37 b	3.66 a	7366 c
LSD(0.05)	23.46	0.46	1671

[1]Root condition rating = 1–5 (1 = healthy roots/no necrosis, 5 = total necrosis).
[2]Bare root transplants produced in soil.
[3]Means with the same letter are not significantly different.
[4]Plug transplants were produced by rooting runner tips in a peat-based (soil-less) potting mix.
[5]LS213 contains *Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% carrier (BioYield,™ Gustafson LLC) was added to peat-based potting mix before rooting of runner tip plants.
[6]Methyl bromide 67:33 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds.
[7]1,3-Dichloropropene (1,3-D, Telone II, Dow AgroSciences LLC, Indianapolis, IN) at 94.6 l ha^{-1}, broadcast shank injected 14 days prior to bedding.
[8]Plantpro 45 (Ajay North America, LLC, Powder Springs, GA) at 890 l ha^{-1} applied in bed through two high flow rate (emitters spaced at 10 cm) drip irrigation lines, 14 days prior to planting.

yield could be an important factor in maintaining profit margins in the post methyl bromide era because prices for early market fruit are higher. Assuming a current per plant cost of 4.5 cents for bare root transplants (Lassen Canyon Nursery, Inc., Redding, CA), 17 cents for plug transplants (Aaron's Creek Farms, Inc., Buffalo Junction, VA), and 19 cents for LS213 plug transplants (Gustafson LLC Plano, TX), the additional cost per hectare for plug and LS213 plug plants is approximately $5142 and $5942, respectively. The additional value of plug and LS213 plug plant yields, calculated using monthly averages for 1998 and 1999, and a yearly average for 2000 (FASS, 2000) show that with methyl bromide fumigation, plug and LS213 plug plant yield values met or exceeded their additional costs in 50% of our trials, regardless of variety. Despite the effectiveness of methyl bromide and the increase in yield with plug plants, the extra cost is only warranted if other economic variables reduce the cost of production per hectare. With Telone fumigation, the 'Sweet Charlie' plug or LS213 plug plants met or exceeded their additional costs in 25% of our trials, while the 'Camarosa' plants did not ever break even. Despite the apparent effectiveness of Telone, the additional cost of plug or LS213 plug plants is not warranted. If the additional costs (direct or indirect) of plug or LS213 plug plants were reduced to approximately $2000 per hectare, then their additional values would meet or exceed their additional cost in 75% of our trials. This analysis does not include the economic impact of other factors associated with plug transplants, such as the flexibility in planting time, the ability to mechanically transplant, reduction in labor expense associated with replanting bare-root transplants, and reduction in numerous expenses incurred due to overhead irrigation for bare root plant establishment (Durner et al., 2002; Waldo and Duval, 2001). A more accurate cost-benefit analysis to determine the practicality of using plug or amended plug transplants should be calculated using current values for individual applications. The fact that strawberry nurseries are highly dependent on the use of methyl

Table 6. 'Sweet Charlie' root weight, root condition, and total yield at the end of the season in Sanford, FL for 2000

	Root Weight (g)	Root Condition[1]	Total Yield (kg ha^{-1})
Transplant type			
Bare root[2]	26.23 b[3]	1.99 a	6246 a
Plug[4]	40.63 a	1.52 b	7238 a
LS213 Plug[5]	31.56 b	1.44 b	7166 a
LSD (0.05)	7.93	0.30	1721
Soil Treatment			
Untreated	31.25 a	2.01 a	7540 a
Methyl Bromide[6]	37.93 a	1.38 b	6746 a
Telone II[7]	31.55 a	1.43 b	7035 a
Plantpro 45[8]	30.37 a	1.79 a	6211 a
LSD(0.05)	9.15	0.34	1987

[1]Root condition rating = 1–5 (1 = healthy roots/no necrosis, 5 = total necrosis).
[2]Bare root transplants produced in soil.
[3]Means with the same letter are not significantly different.
[4] Plug transplants were produced by rooting runner tips in a peat-based (soil-less) potting mix. [5]LS213 contains *Bacillus subtilis* strain GBO3 + *Bacillus amyloliquefaciens* strain IN937a at 10^9 CFU/liter in 2.5% carrier (BioYield,™ Gustafson LLC) was added to peat-based potting mix before rooting of runner tip plants.
[6]Methyl bromide 67:33 methyl bromide (MeBr):chloropicrin at 425 kg ha^{-1}, shank injected in beds.
[7]1,3-Dichloropropene (1,3-D, Telone II, Dow AgroSciences LLC, Indianapolis, IN) at 94.6 l ha^{-1}, broadcast shank injected 14 days prior to bedding.
[8]Plantpro 45 (Ajay North America, LLC, Powder Springs, GA) at 890 l ha^{-1} applied in bed through two high flow rate (emitters spaced at 10 cm) drip irrigation lines, 14 days prior to planting.

bromide for soil fumigation in order to produce certified pathogen-free bare root transplants should also be considered. The loss of methyl bromide for use in strawberry nurseries is likely in the near future, and at that point, a value must be assessed for pathogen-free planting material.

The potential reduction in water use associated with plug transplants has economic and environmental benefits in addition to reducing disease and weed pressure. The necessity for use of overhead irrigation on the entire experimental plot in these trials was to insure establishment of plots with bare root transplants. This eliminated a more accurate assessment of the performance of plug and amended plug plants under the exact conditions in which they should be grown. Additional larger scale studies are necessary to accurately evaluate the entire system including changes in cultural practices associated with the different transplant types.

Development of new strategies for strawberry transplant production that improve root health and reduce reliance on methyl bromide soil fumigation is extremely important. Plug transplants have exhibited beneficial effects and potential for incorporation into current strawberry production systems. Further biological and economic evaluations of plug transplants for introduction of beneficial organisms such as PGPR are necessary although preliminary studies are encouraging. Greater acceptance and use of strawberry plug transplants by growers will provide further incentive for development of beneficial organisms for use on these types of transplants.

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